ENVIRONMENTAL RISK ASSESSMENT OF RED MUD CONTAMINATED SOIL IN HUNGARY

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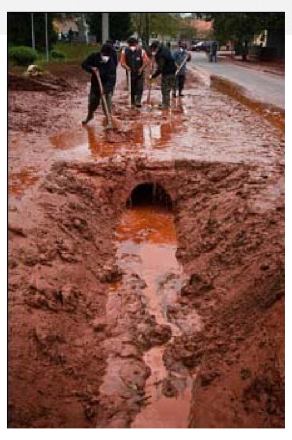
The red mud catastroph in Hungary

On the 4th October 2010, the corner of the No. 10 red mud storage pond at the alumina production facility in Ajka, Hungary broke. 800 000 m^3 red mud (RM) of high alkalinity (pH 13) streamed with high velocity, has swept bridges, houses and unfortunately led to human casualties; 10 people died, 60 injured. It flooded three villages, thousands of hectares of agricultural land and a 10 km long section along the Torna valley, the upper watershed area of Marcal River, ending into Rába River, which reaches the Danube.



Steps of the risk management of RM flooded soil

- Creating the conceptual risk model (Figure 1)
- Site assessment and monitoring;
- Laboratory analyses, ecotoxicological testing, simulations;
- Risk assessment and risk characterization;
- Testing / monitoring Na+ / sodification;
- Risk reduction by removal or incorporation of red mud;
- Risk reduction by revegetation;
- Validation and verification of the applied technologies.

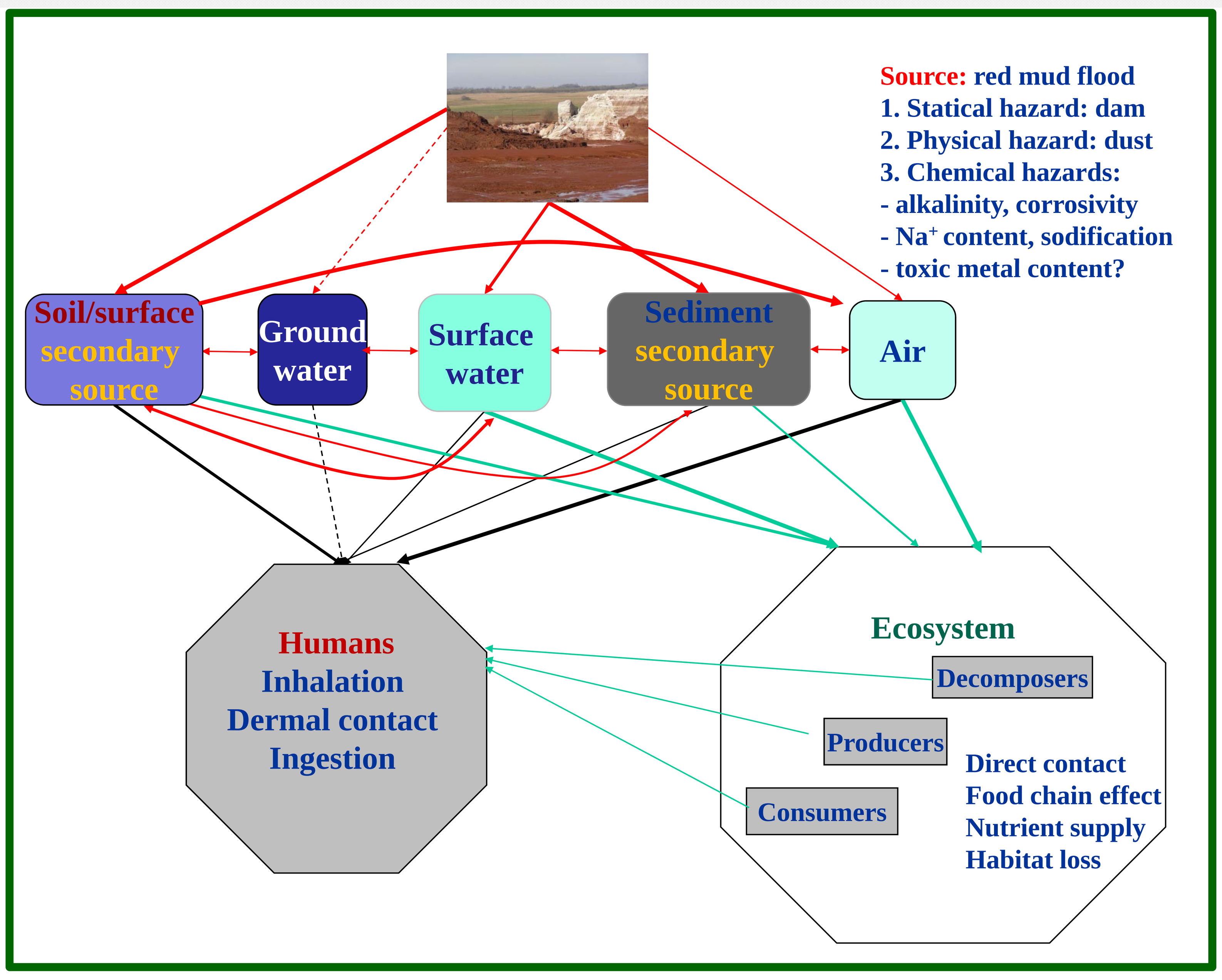


Figure 1. The conceptual risk model of the red mud flood

Hazard / risk inventory

Infiltration of the alkaline liquid phase into soil and groundwater
- Soil and groundwater alkalinization, increse in Na^+ content
- Changes in the chemical form / mobility of nutrients / toxic metals;
- Changes in soil nutrient quality / quantity and water cycling;
- Increased risk of sodification;
- Soil and groundwater toxicity;
- Plant growth inhibition, limited nutrient supply;
- Caustic / corrosive effect of the contaminated soil on humans;
- Detrimental effect of contaminated soil / ground water on humans.

Fine grained red mud on the soil surface and in the soil
- RM plugs the soil pores resulting anoxic conditions in the soil;
- Damaging effect of anoxic conditions on plants and soil living org.

Hazards subsequent to drying of the fine grained red mud
- Dusting: threat to humans by inhalation, hazard of PM10 / PM2.5;
- Hazard due to caustic effect, threat to humans by ingestion;
- Supposed toxic element content.

Plowing (incorporating) RM into soil
- Increased alkalinity, Na and Fe content;
- Increased sodification potential;
- Toxicity to soil ecosystem and cultivars.

Revegetation/planting
- Reduces dusting but might increase toxicants bioaccumulation;
- Plant growth inhibition and secondary human poisoning by plants.

Risk assessment results

- Dust inhalation: after slight increase of PM10 during clean-up activities, it went back to the former level
- Inhalation / ingestion of alkalinity: negligible risk
- Dermal corrosion / irritation
  - RM, Freshly discharged: RCR = 10 — very high risk
  - RM on the top of the soil: RCR = 3–5 — high risk
  - RM incorporated at 10%: RCR = 1,001–0,01 — negligible risk
- Risk of alkalinity and Na+ to soil quality
  - RM on the top of the soil: RCR = 3.4 — high risk
  - RM removal: RCR = 0.1 — negligible risk
  - RM incorporation at 5%: RCR = 0.2 — negligible risk
  - RM incorporation at 10%: RCR = 0,8–1.6 — moderate–significant
- Toxic metal contents of RM: As, Cr, Ni and Se have been increased
  - RM on the top of the soil: RCR = 1.5–5.6 — significant risk
  - RM removal: RCR = 0.4–0.6 — moderate risk
  - RM incorporation at 5%: RCR = 0.4–0.6 — moderate risk
  - RM incorporation at 10%: RCR = 0.4–0,8 — moderate risk

Direct toxicity testing

Soil samples (RM flooded and reference) from the field were tested in the laboratory using bacteria, plants and collembola as testorganisms.

RM removal before sampling: not significant difference
RM incorporation (10–20%): slight deviation from reference
Deeper layers: (>30 cm): no difference compared to reference.

Simulation tests

Adverse effect of incremental (from 5% to 100%) RM concentrations in soil was measured in soil microcosm tests. We determined the highest no effect percentage from the inhibition effect on bacteria, plant and collembola after RM incorporation.

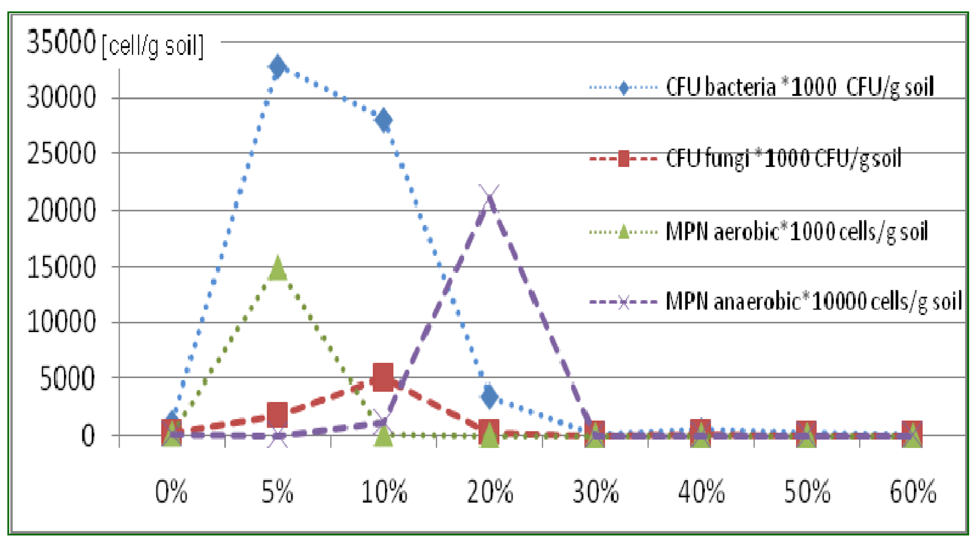
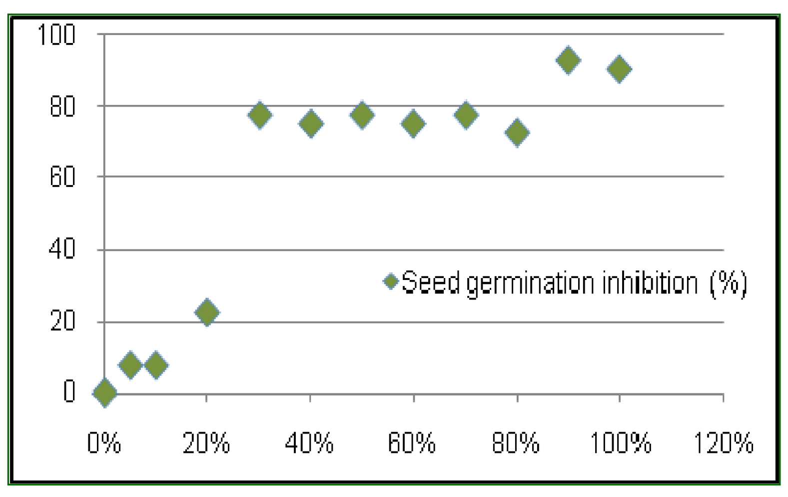


Figure 2. Microbial cell numbers in soil after RM incorporation at 0—60%

Figure 4. Inhibition of plant root and shoot growths in soil after RM incorporation at 0—60%



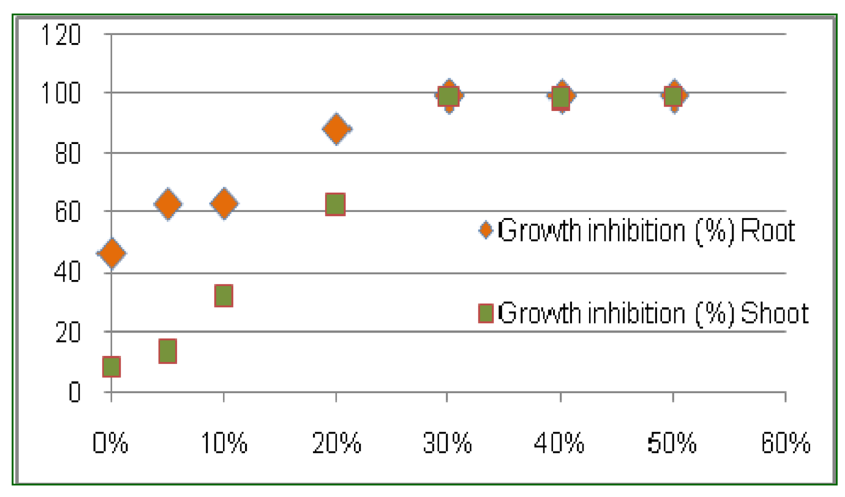
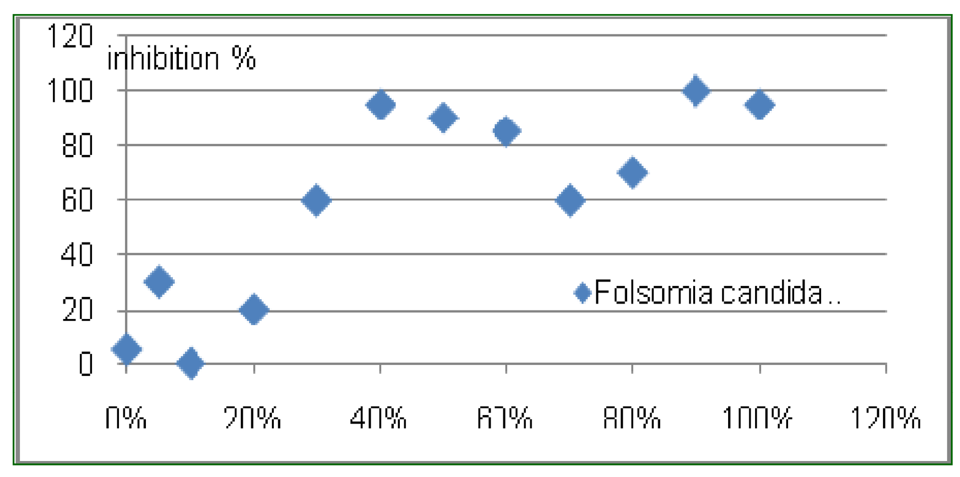


Figure 3. Inhibition of plant germination in soil after RM incorporation at 0— 100%

Figure 5. Inhibition of Collembola in soil after RM incorporation at 0— 100%



Risk reduction steps in the Torna valley

- Protection of human life and exclusion of life threatening hazards;
- Isolating the dyke and neutralizing alkaline flux to protect waters;
- Cleaning residential areas, open surfaces from RM and debris;
- Gradual cleaning of the river bed;
- Removal of the secondary contaminant sources: soil, sediment;
- Risk reduction of soil by removal or incorporation of red mud;
- Long term monitoring of the fate and transport of Na and alkalinity;
- Revegetation and verification of the soil treatment technologies.

Conclusions

A seemingly simple situation, – such as agricultural soil flooded by suspended solid in alkalic liquor – becomes extremely complex, when interacting with environmental compartments. A detailed risk assessment made the situation clear and supported decision making.

Residual human risks after cleaning the site are moderate or negligible. Incorporating incremental amounts of red mud into soil microcosms has forecasted a 8–10% mixing dose to be acceptable from inhibition point of view, but sodification still remains a threat. Na-ion-concentration increased significantly, but significant Na-attenuation (half-life time: three months) may reduce its risk on the long term.